

Experimental study on bolt torque–tension relationship for different washer and nut combinations

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Abstract. This experimental study was conducted to determine nut factors based on four combinations of washers and nuts. A prestressing force was applied to a long reinforcing bar using the torque–tension method. All the sets exhibited a linear trend. The nut factors for combinations of the flat washers and hex nuts, spring washers and hex nuts, flat washers and heat-treated nuts, and flat washers and self-locking nuts were 0.228, 0.224, 0.299, and 0.397, respectively. Additionally, the relaxation of the flat washers and hex nuts in a relatively long-term period (40 days in this study) was evaluated, and eight specimens subjected to various initial prestressing forces were analyzed. The average change in prestressing force was -3.98%. It is necessary to consider prestressing force loss for relatively long-term when prestressing force is applied to a long reinforcing bar.

Keywords: nut factor, prestressing force, relatively long-term relaxation; torque–tension, washer and nut

1. Introduction

The prestressing method is a technique in which internal stresses are applied to a structure by introducing prestressing to a strand or bar (Kim *et al.* 2021, Lee *et al.* 2014b). Many studies have shown that structures reinforced with prestressing exhibit improved structural performance, such as shear, flexure, and energy dissipation (Kim and Kang 2019, Lee *et al.* 2015, Yang and Kang 2011). Some researchers utilized these advantages and applied the prestressing method to repair and reinforce structures (Hwang *et al.* 2020, Lee *et al.* 2014a, Yang *et al.* 2007, Yang *et al.* 2020). For example, prestressing forces have been introduced with nut fastening using a thread at the end of a long steel bar or deformed reinforcing bar. Prestressing forces are typically applied to steel bars or deformed reinforcing bars using the torque control method, which provides tensile forces through the torque generated by nut tightening. Thus, it is possible to easily introduce prestressing forces. Furthermore, it is necessary to evaluate the relaxation after the initial introduction of prestress. For typical bolt–nut combinations, the torque force (T) can be obtained by multiplying the diameter (d_b), tensile force (F), and nut factor (k), where the conventional value of the nut

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